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ENGINEERING EXPERIMENT STATION  
AERONAUTICAL ENGINEERING DEPARTMENT

PROGRESS REPORT

March 1953



INJECTOR JET

Contract No. N6Or1-071-(09)

NR 220-004

UNIVERSITY OF ILLINOIS  
URBANA, ILLINOIS

March 30, 1953

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Prepared by: R. W. McCloy

Experimental work on the Ejector Jet project has been underway since September 1952. The project has been plagued with numerous difficulties since the inception of the experimental program. None of these difficulties has in any way indicated that the basic principles of the ejector jet are fallacious.

The main difficulties encountered with the test program have been due to the following three factors which of necessity are encountered in the construction of an efficient ejector jet, namely: high temperature (1200 or 1300°F), high pressure (1000 to 3000 psi), and the use of a non-lubricating fuel (methanol).

To better indicate the sources of difficulty, the starting and operating procedure will be presented. In the schematic diagram (Fig. 1), with ram air provided the fuel pump<sup>(1)</sup> is started and flow at this point is entirely through the fuel bypass. The spark plug<sup>(2)</sup> is energized and the starting fuel valve<sup>(3)</sup> is opened. The ejector jet is then operating as a ram jet and the regenerative heating coils vaporizing<sup>(4)</sup> and superheating<sup>(5)</sup> are absorbing heat and raising the temperature of the alcohol. When the temperature is sufficiently high (800-1200°F), fuel is allowed to pass to the primary nozzle<sup>(6)</sup> by opening of a main fuel valve<sup>(7)</sup> or by opening a self-sealing nozzle<sup>(6)</sup>. The jet-pump action of the vaporized alcohol then induces air and compresses the air-fuel mixture, and this mixture is burned in the combustion chamber. The starting air may now be shut off and the ejector jet then operates as a ram jet without ram.

Enough heat transfer area must be supplied in the vaporizer coils that heat can be absorbed through the walls in sufficient quantity to obtain design temperature (1300°F) in the fuel for the condition of

maximum fuel flow. This of course results in too great a heat absorption at lower fuel flows. To control this fuel heating, a desuperheating system was incorporated. Since the major portion of the heat absorbed by the fuel is in the 20 ft. of superheater coils rather than the 60 ft. of vaporizer coils, control can be obtained by injecting cold alcohol into the vapor as it enters the superheater coils.

Operation of the bypass temperature control is actuated by a thermocouple placed in a tube immersed in the superheated alcohol at point <sup>(8)</sup> where the superheater tube leaves the combustion zone. The thermocouple output passes to a modified Bristol Flap-Actuator controller. Here the signal is amplified and converted into an open or close signal to the motor operating the bypass valve. There is a "rate of change" circuit in the controller which causes it to anticipate approach to the controlled temperature and causes open or close pulses to be sent to the valve motor.

Some of the difficulties which have been encountered and the solutions obtained will be discussed below:

#### Pump

As has been reported previously, a small rotary pump to handle low viscosity fluids at pressures up to 3000 psi is not readily available. The Superdraulic Corporation of Detroit, Michigan has cooperated in the adapting of their rotary piston pump for pumping alcohol. The standard version of this pump is designed for operation with hydraulic fluid. Lubrication of the sliding surface between the fixed pintle (which incorporates the fluid flow passages and the valve ports) and the rotating drum, which has bored cylinders in it for the pistons,

is normally accomplished by the viscosity of the hydraulic fluid.

When methyl alcohol was used as the fluid, seizing of the sliding surfaces occurred after about 5 seconds.

A bronze insert in the cylinder drum as a bearing insert gave only slightly better performance.

A carbon insert operated very well below 2000 psi, but at higher pressures the insert failed due to low mechanical strength.

A modification which used silver plating on one sliding surface and tin plating on the other gave better performance. However, after a few hours of running, the clearance increased to a point that the leakage of alcohol into the separate lubrication system became excessive.

A new plating material has now been incorporated, and the leakage of alcohol into the lubrication system has been reduced but not eliminated.

This pump is not considered to be the final answer, but valuable data concerning operation with methyl alcohol have been obtained.

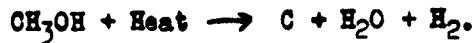
This pump has an excessive weight for airborne operation because of its low rotational speed. It is felt that a rotary screw pump operating at turbine speeds would be more suitable for airborne operation.

#### Fuel

From the performance calculations shown in Report 9-8 "Performance of the Ejector Jet", it was determined that a greater specific thrust could be obtained by using gasoline or kerosene as the fuel rather than methanol.

However, when gasoline and kerosene were used in the experimental installation, cracking of the hydrocarbons to coke and tar occurred, and the vaporizing tubes were rapidly clogged.

When methanol is used, some cracking occurs, but, so far, only minor difficulties have been encountered. The reaction seems to be



The free carbon which is formed is small in amount and generally passes on through with the vapor. However disturbances in the flow due to constrictions may cause an accumulation of carbon. This carbon does not adhere to the tubes as did the coke and tar obtained from operation on gasoline and kerosene.

#### Primary Nozzles

The controlled-free-expansion nozzle (Fig. 2) had two faults due to inaccurate machining. The first was that the nozzle would not seal off the flow completely due to a slight misalignment of the central body and the nozzle throat. This resulted in the installation of a fuel shut-off valve at (?) in Fig. 1. Second, since the design throat area of 0.128 sq.in. was to be distributed around a four-inch circumference, the throat opening (without correction for boundary layer) was only 0.032 in. The eccentricity of the central body then, would cause a dissymmetry in the flow which was objectionable.

In operation, the nozzle behavior was as follows: When the fuel shut-off valve (?) in (Fig. 1) was opened, liquid alcohol, which fills the tubes from the starting fuel bypass(9) to the nozzle, was sprayed out in a conical sheet with an included angle of about 90°. Most of this liquid spray would fall outside of the ejector-jet intake. However, when vaporized alcohol flowed through the nozzle, the predicted Prandtl-Meyer expansion took place, and the vaporized methanol followed the contour of the central body and the expansion to supersonic velocities took place.

Due to the difficulty of adjusting the central body under the high pressures and temperatures involved, this type of nozzle has temporarily been shelved. (Further investigation of the controlled-free-expansion supersonic nozzle will be conducted in connection with a Master's thesis project.)

In order to permit adjustment of the central body under high pressure and temperature, the nozzle shown in Fig. 3 and 4 was built. Sealing is insured by the bulge on the central body and 120° conical seat. When the nozzle is closed completely, a 1/4 in. wide circumferential seat provides contact without seizing. At low pressures some leakage occurs, but at higher pressures the alcohol in the nozzle chamber exerts an unbalanced pressure on the bulge on the central body and causes a high seating pressure which prevents leakage. As soon as the nozzle is opened, pressure is exerted on the opposite side of the bulge as well, and the forces on the central body are nearly balanced. It is then possible to vary the nozzle opening under load.

The nozzle is designed so that complete expansion is obtained at design operating pressure, temperature, and rates of fuel flow. At all other pressures, temperatures, and rates of fuel flow, the nozzle expansion is incomplete. Free expansion to ambient pressure then occurs.

Initially considerable difficulty was encountered due to seizing of the screw threads in mating parts. This has largely been eliminated by using brass inserts so that no steel-steel contact exists except at the valve seat. As a further precaution, dry molybdenum-sulphide lubricant is used as a non-seizing compound in all of the threads.

Valves

Because of the leakage in the non-seating nozzle, a fuel-shut-off valve was installed [(7) in Fig. 1]. Several difficulties were encountered here. The original valve was a needle valve where the flow was throttled and had its direction changed twice. Carbon accumulated at the flow constriction and blocked the flow.

A cylindrical plug-type valve was then built, and the carbon accumulation was solved, but valve seating and seizing was then a problem. The plug valve was then modified to incorporate a 10° taper on the plug and lubrication was obtained by dipping the plug in water glass, wiping so that the surface was only slightly moist, and then coating with molybdenum disulphide. The water glass (which softens at 2000°F) was used as a bonding agent to prevent the washing off of the molybdenum disulphide. This valve was fairly effective, but the valve was removed from the unit when the self-sealing primary nozzle was developed (see above).

Some carbon accumulation has been noted in the starting fuel valve [(3) in Fig. 1], and in the starting fuel nozzle (10) but so far no difficulties have been encountered.

The Controller

Originally the fuel bypass for desuperheating was joined at the midpoint of the vaporizing coil. Insufficient control was obtained, so the bypass was joined to the entrance of the superheater coil.

When the controller was turned on during the preliminary heating of the fuel, the bypass valve may start to open at a temperature as low as 800°F if the heating is rapid. By the time the fuel shut-off valve was opened, the bypass valve was wide open. Then as flow through

the actuating nozzle started, the flow through the bypass valve was such that the methanol cooled down before the primary fuel had a chance to heat it up. This necessitated leaving the controller in the off position until the primary nozzle was opened.

With the self-sealing primary nozzle, the fuel shut-off valve is eliminated. Then as the fuel temperature reaches 800 to 1200°F, the primary nozzle is opened slightly and the controller cut in. The fuel flow, and the fuel pressure may then be varied independently and the controller will maintain a constant operating temperature within the limits of the effectiveness of the bypass system. These limits have not yet been determined.

#### The Vaporizer

The vaporizer is made from 20 ft. lengths of columbium-stabilized stainless steel. The sections of tubing are welded together with an atomic-hydrogen torch. The welds are sound and free from slag inclusions since no flux is used in the welding process. Due to the high welding temperature (6000-9000°F) and the thin wall (1/16 in.) of the tube care has to be taken to prevent boiling of the metal which results in pin holes in the weld. One such pin hole, which showed up only after some running time, sprayed a small jet of alcohol on to one of the vaporizer coils and eventually caused cracking, probably due to the local quenching action. Carbon pickup which occurs in the mild steel primary nozzle has caused no difficulties in the stainless steel vaporizer tubes.

To make the flame holder, spark plug, starting fuel nozzle, etc. readily serviceable, stainless steel Ermeto unions have been welded

into a bulkhead. The aft vaporizer coils are then coupled to one side of the bulkhead and the fuel inlet, bypass fuel, and the fuel line to the nozzle are connected to the forward side of the bulkhead. So far no trouble have been encountered with these fittings other than insufficient tightening of the fitting so that the sleeve does not "groove" the stainless tube properly.

Since the vaporizer tubes are "tacked" together with stainless steel "arc" rod, there is no seal against combustion gasses flowing through the interstices between adjacent tubes. In order to seal these interstices and also insulate against heat loss from the vaporizer, a 1/4-inch insulating layer of vermiculite (expanded mica) bonded with water glass was baked ( $200^{\circ}\text{F}$ ) on the outside of the vaporizer. A metal shell covers this insulation and extends beyond the downstream end of the vaporizer. The thrust nozzle is at present an insert of luminite cement and vermiculite formed with a wire screen reinforcement. Variation of the thrust nozzle throat area can then be obtained by breaking out the old nozzle insert and replacing it with a new insert with a different throat area.

#### Insulation

To provide insulation of the supersonic and subsonic diffusers, a blanket of 1/2-inch glass wool has been cemented to the surface with  $2000^{\circ}$  water glass.

When, at low fuel pressures, flash back occurs, burning starts at the primary nozzle and continues through both the subsonic and supersonic diffusers. The glass wool melts under these conditions, so Fiberfrax ceramic fiber is being substituted.

Flash back also sometimes results in melting off some of the silver-soldered pressure pickups.

The bypass-valve actuating motor has, on occasion, become overheated due to "flash back" and, as a result, has had to be replaced.

#### Ignition

Ignition has been a primary source of difficulty. The necessity of projecting the electrodes into the region where combustible air-fuel mixtures exist, necessitates either removal of the spark plug after initiation of combustion or operation in a high-temperature zone. Use of tungsten electrodes has eliminated the melting of electrodes, but the shielding necessary to provide a low velocity ignition region is still causing difficulty. To prevent melting here, a ceramic shield is now being tried.

#### Rotameters

The rotameters used for measuring fuel flow were surplus gasoline-measuring instruments. After a period of operation on alcohol, blisters appeared on the "floats" which were some type of synthetic material. After a considerable period of exposure the "floats" disintegrated, so they were replaced by aluminum "floats" and recalibrated.

Due to the leakage of alcohol into the pump-lubrication system, the flow shown by the rotameters is fallacious, so another flow measurement system will have to be tried.

#### Flame Holders

Various types of flame holders have been tried. All of them are effective in holding the flame, but, when flash back occurs,

they melt out. A flame holder made of tungsten electrodes is now being tried. Under starting conditions "torching" occurs and the flame is orange, but when the primary nozzle is open, the flame is blue and is visible for only six inches beyond the thrust nozzle.

Pictures of the test setup are shown in Fig. 5-10.

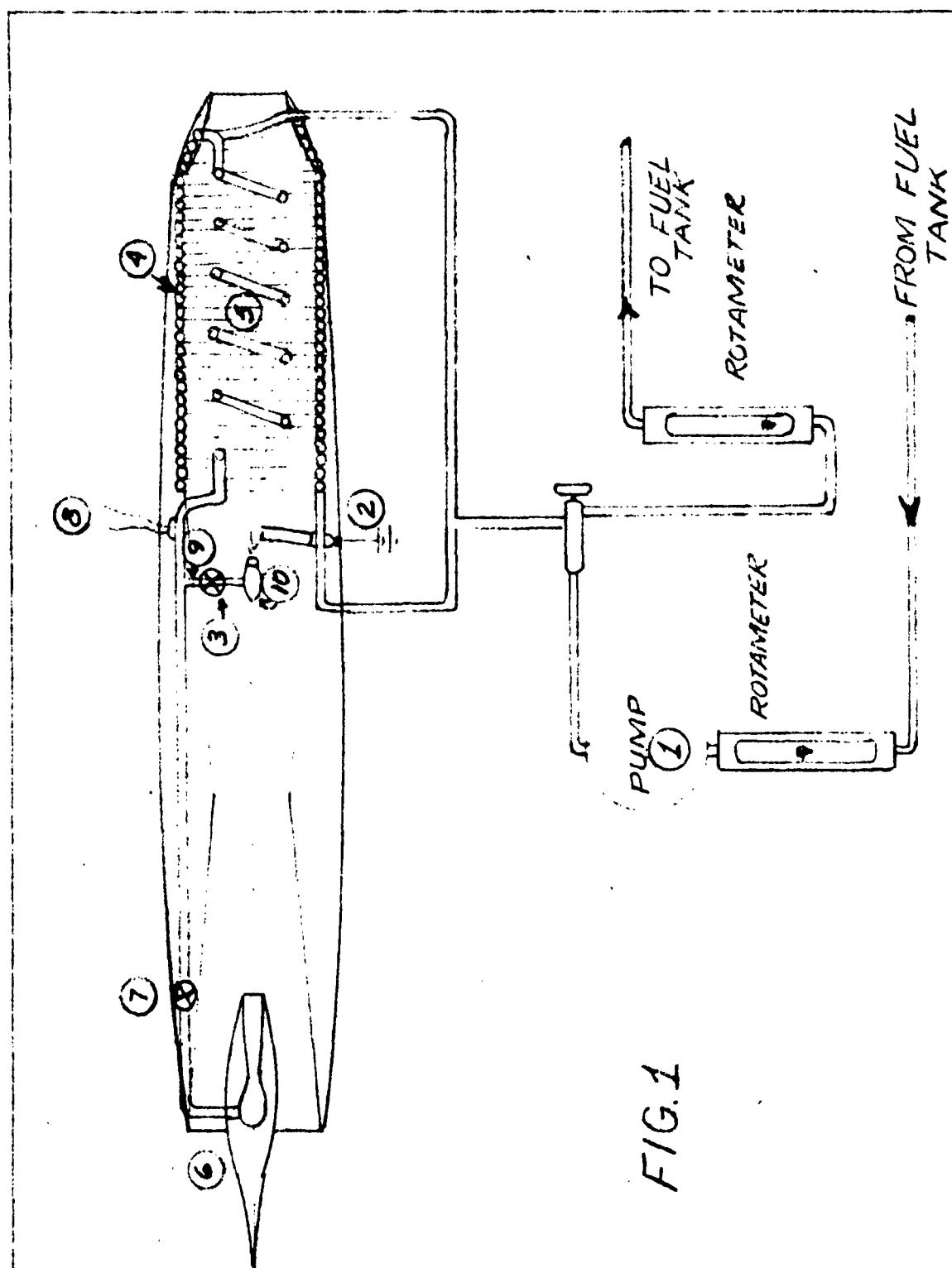


FIG. 1

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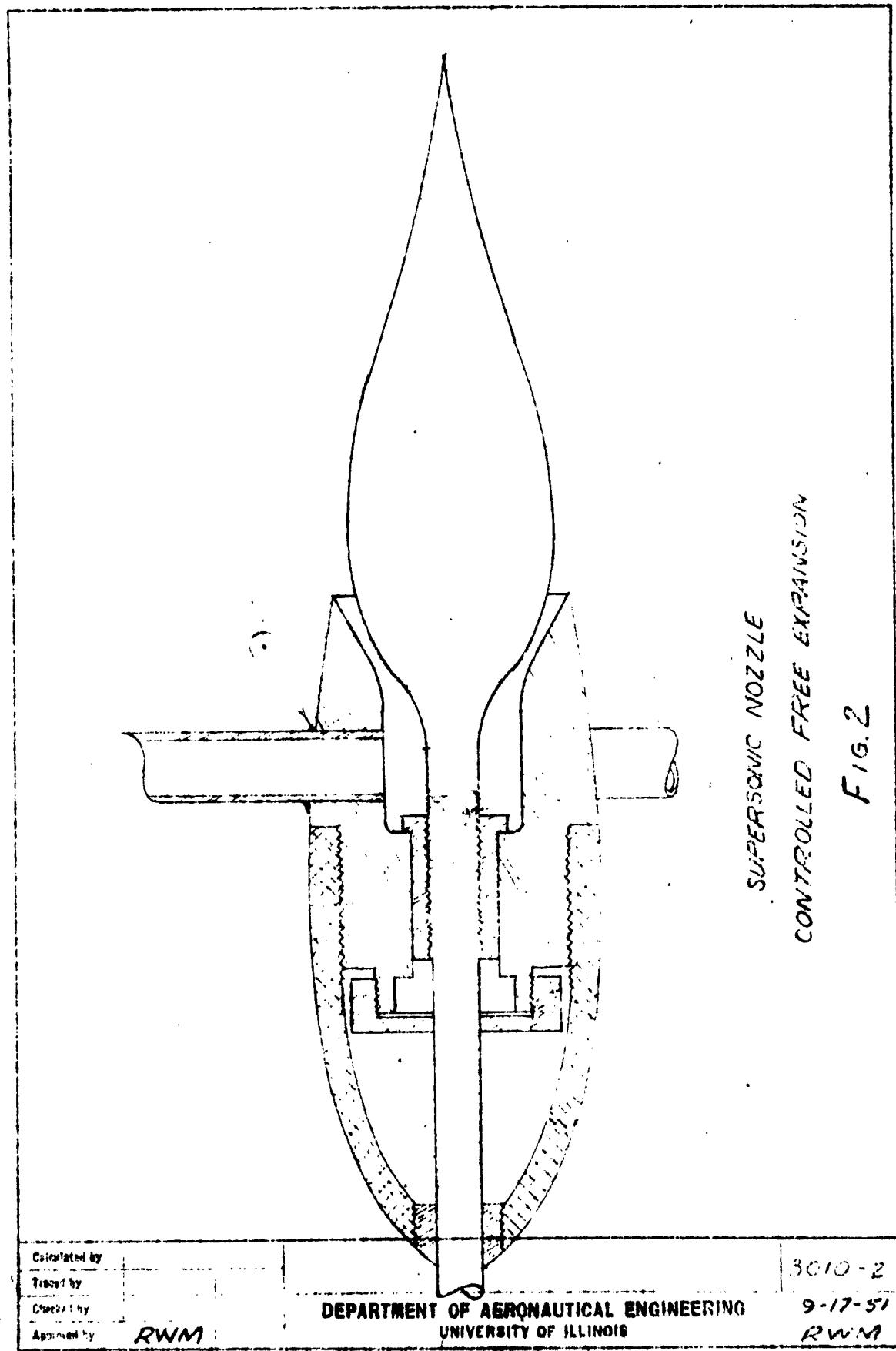


FIG. 2

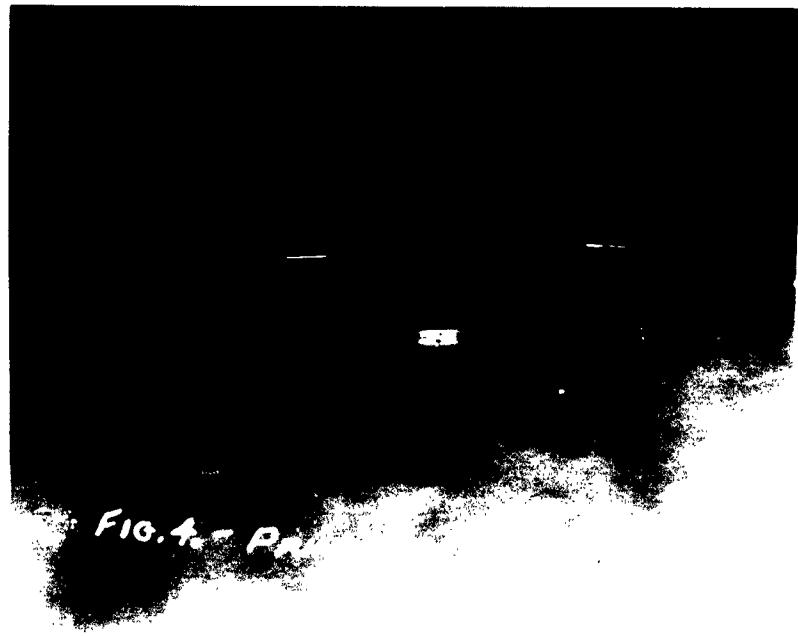
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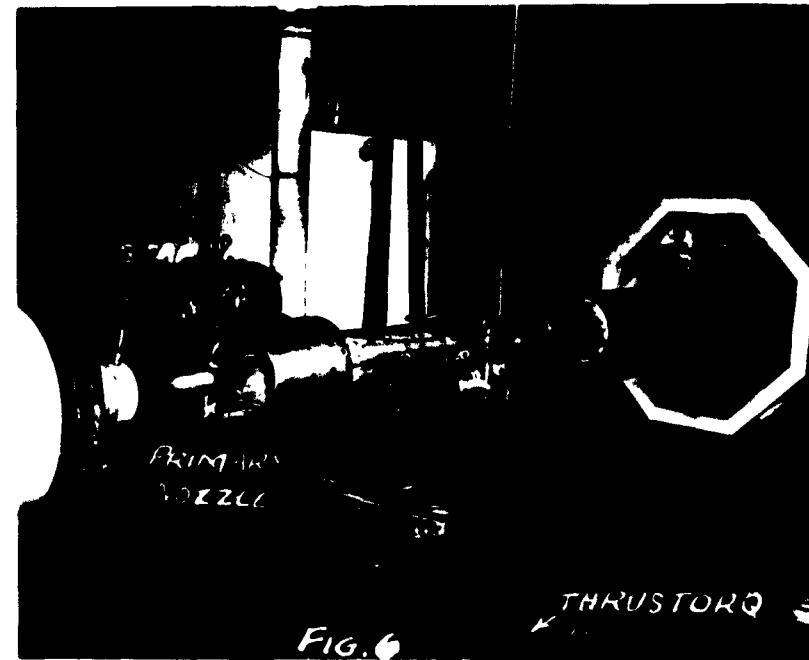
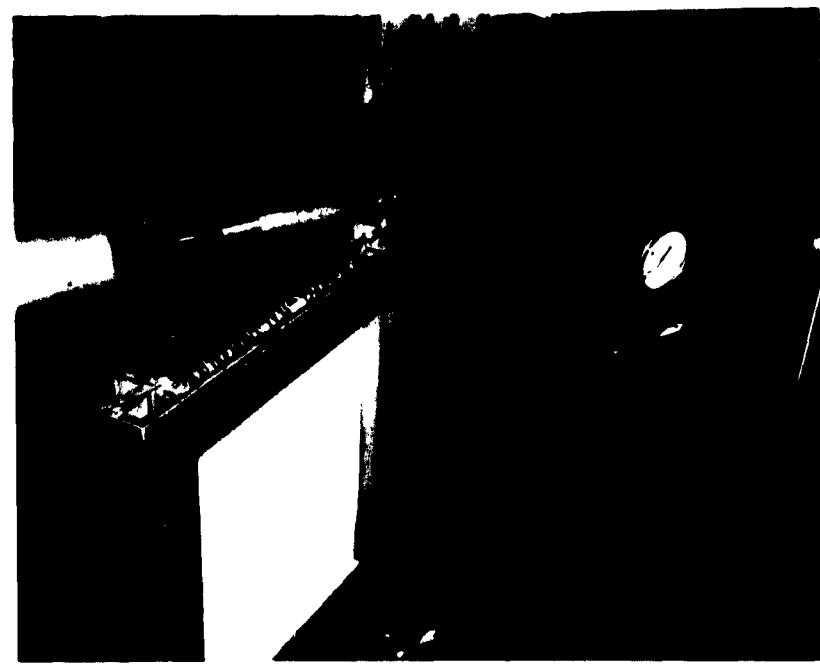
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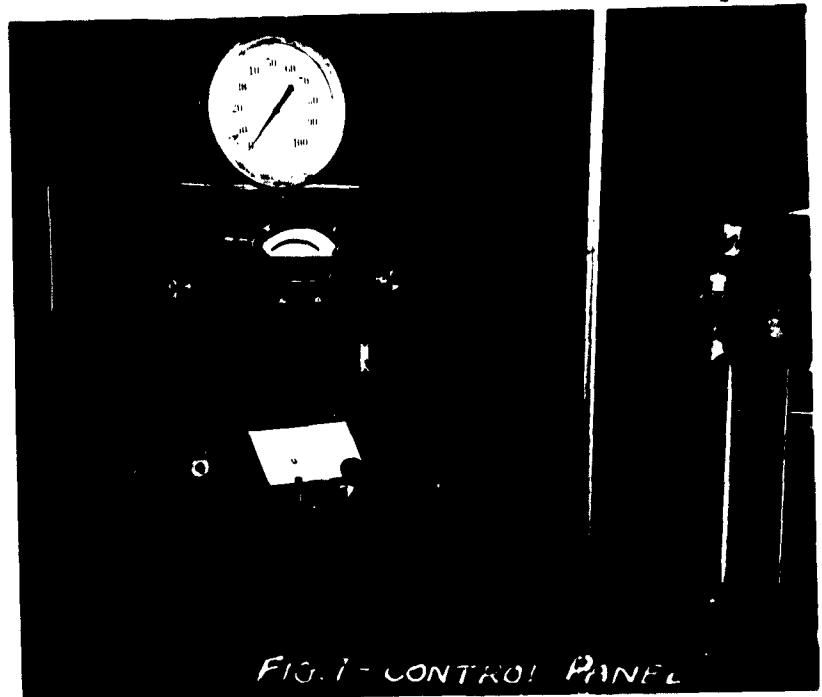


FIG. 1 - CONTROL PANEL

